FuelCell Energy
World Leader in Ultra-Clean Power

Stationary Fuel Cell Power Systems with Direct FuelCell Technology Tackle Growing Distributed Baseload Power Challenge

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Global demand for electric power is on the rise, while tolerance for pollution and potentially hazardous forms of power generation is on the decline. Traditional forms of power generation — primarily made up of centralized fossil fuel plants — are becoming less favored in lieu of clean, distributed power generation technologies.

Emissions from coal and other fossil fuel-powered plants include large amounts of carbon dioxide (CO2) greenhouse gas and pollutants that include nitrogen and sulphur oxides (NO_x and SO_x). In addition, all forms of centralized power generation use a grid of high-voltage transmission lines to carry energy to consumers. These transmission lines represent a problematic infrastructure for the utilities, due to real or perceived health threats, NIMBY issues, and the loss of energy during transmission — as much as 20% depending on the distance from the central power source to the user.

Unlike the backup power solutions normally associated with distributed generation (DG), new technologies offer baseload power solutions that operate 24/7 and can dramatically reduce dependence on the power grid. Stationary fuel cells, wind farms, and solar arrays are coming of age, while micro-turbines and combustion generators continue to improve. However, only fuel cells and fossil fuel-based generation technologies offer 24/7 distributed power. Of this group, fuel cells offer the cleanest and most efficient form of distributed power generation available.

Why Fuel Cells?

The need is clear and well recognized for clean, safe, and reliable forms of energy that can provide prescribed levels of power consistently, and on demand. Yet, most forms of non-combustion electric generation have limitations that impact widespread use of the technology, especially as a primary source of electric power (i.e., baseload power). Solar energy, for example, depends on the sun. Extended days of cloudy skies can severely limit the generation of electricity, and power availability is generally considered to be between 25 to 35%. Wind turbines are designed to turn kinetic energy into electricity. They too, depend on factors that cannot be controlled. In this case, the presence of wind and a certain minimum wind velocity are required. As a result, power availability is judged to be in the range of 30 to 35%. Geothermal sources require heat energy from underground geothermal fields, which mean they are restricted to certain geographic locations. Similarly, hydroelectric plants are confined to locations near major rivers and are also somewhat constrained by nature. Thus, without adequate and consistent sun, wind, heat, and water flow, such sources of power generation are limited by the whims of nature and cannot be considered as reliable sources of baseload power when and where needed.

Fuel cell technology, on the other hand, has advanced to the point where it is now a viable challenger to combustion-based plants for growing numbers of baseload power applications. Today, fuel cells are reaching their potential as the cleanest and most reliable sources of distributed power generation. With 95% power availability and electric power generation efficiency of 47%, they represent a viable means of producing "Ultra-Clean" power, reliably, consistently, and on demand.

While the need to ensure the availability of hydrogen has been seen as a concern in the operation of fuel cells, Direct FuelCells® (DFCs®) developed by FuelCell Energy, Inc. are unaffected by such limitations because they use natural gas and biofuels (gases from food processing and wastewater treatment) as a source fuel. Furthermore, with system adjustments, these fuel cells can also operate with a wide range of alternate fuels, including ethanol and propane. Direct FuelCells have even been shown to generate clean power from diesel fuel and coal gas, fuels traditionally considered to be high pollution sources. DFCs internally reform hydrogen from the source fuels and emit dramatically reduced CO2 greenhouse gas compared to fossil fuel power plants, and only negligible amounts of pollutants, such as NO_x and SO_x.

why
fuel cells?

How Fuel Cells Work

In essence, fuel cells are electrochemical devices that combine fuel with oxygen from the ambient air to produce electricity and heat, as well as water. The non-combustion, electrochemical process is a direct form of fuel-to-energy conversion, and is much more efficient than conventional heat engine approaches. CO2 is reduced, due to the high efficiency of the fuel cell, and the absence of combustion avoids the production of NO_X and particulate pollutants.

Fuel cells incorporate an anode and a cathode, with an electrolyte in between, similar to a battery. The material used for the electrolyte and the design of the supporting structure determine the type and performance of the fuel cell. Figure 1 illustrates the process for FuelCell Energy (FCE) molten carbonate fuel cells (MCFC).

Fuel and air reactions for the molten carbonate Direct FuelCell occur at the anode and cathode, which are porous nickel (Ni) catalysts. The cathode side receives oxygen from the surrounding air. As can be seen in Figure 1, hydrogen is created in the fuel cell stack through a reforming process, which produces hydrogen from the reforming reaction between the hydrocarbon fuel and water. The gas is then consumed electrochemically in a reaction with carbonate electrolyte ions that produces water and electrons.

The electrons flow through an external circuit to provide the power to the fuel cell load, and then return to be consumed in the cathode electrochemical reaction. The O2 supplied to the cathode, along with CO2 recycled from the anode side, reacts with the electrons to produce carbonate ions that pass through the electrolyte to support the anode reaction. The electron flow through the external circuit produces the desired power (DC current). An inverter is used to convert the DC output to AC.

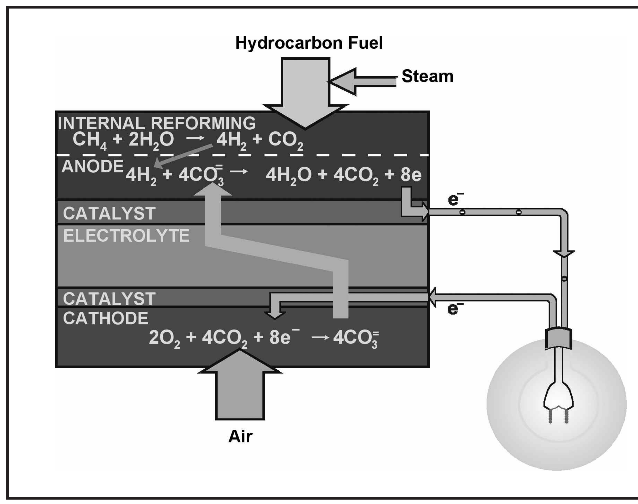

Figure 1. Fuel Cell Processes for a Direct FuelCell

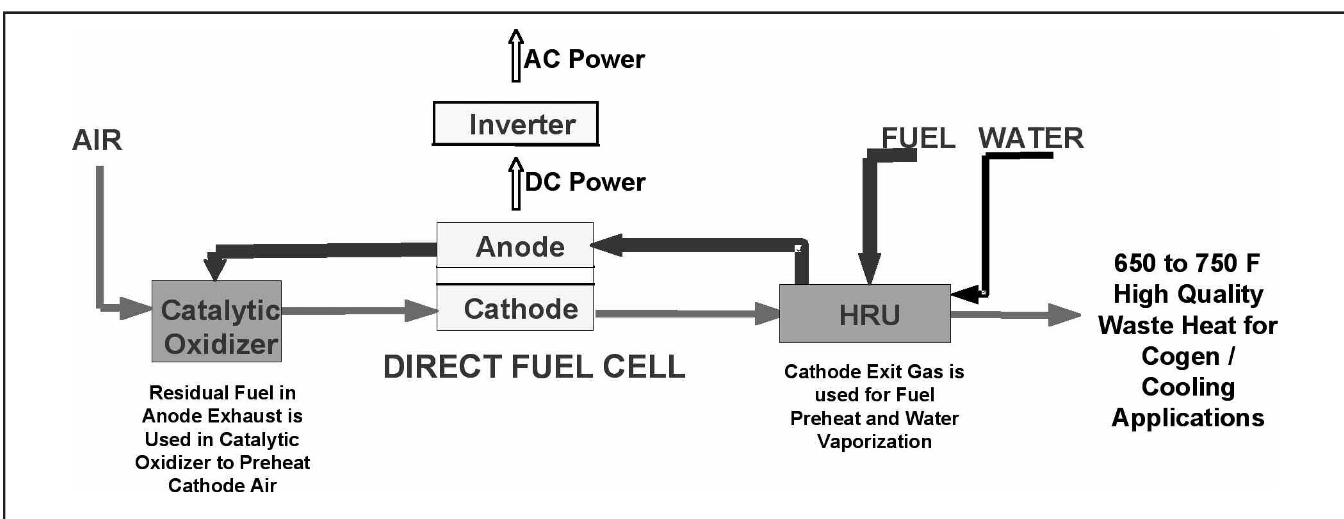

Figure 2. Block Diagram of a Molten Carbonate Direct FuelCell

A DFC powerplant consists of the fuel cells described above (arranged in stacks to provide the required system voltage and power) and the equipment needed to provide the proper gas flow and power conversion, which is referred to as Balance of Plant (BOP). The power plant process is illustrated in Figure 2. Fuel and water are heated to the required fuel cell temperature in a heat recovery unit (HRU), which transfers heat from system exhaust gases. The heated humid fuel stream is sent to the fuel cell stacks where, as described above, the fuel is converted to hydrogen, most of which is used in the electrochemical reaction. Residual fuel — i.e., fuel not consumed in the electrochemical reaction — is supplied to a catalytic reactor to heat incoming air. The heated air flows to the cathode to provide the cathode reactants (oxygen from the air and carbon dioxide from the anode reaction). Cathode exhaust gas exits the system through the heat exchanger used to preheat the fuel and water supplied to the HRU.

Figure 3 shows a typical DFC power plant, with a cutaway illustration of one of the fuel cell modules, showing the fuel cell stacks within the module. There are two main pieces that make up the balance of plant equipment: the mechanical balance of plant (MBOP), and the electrical balance of plant (EBOP). The MBOP consists of such functions as water and fuel treatment, preheating and humidification of the fuel to be supplied to the anodes of the fuel cells, and supply of the air to the system. The EBOP encompasses such subsystems as the DC/AC converter, power metering, switching equipment, and the voltage transformer.

As with other types of power plants, fuel cells can offer the benefits of cogeneration, known as CHP (combined heat and power). A bottoming process, in that heat can be extracted in the production of electric power, cogeneration using fuel cells can represent a significant opportunity to increase the efficiency of the power plant. A diagram showing the setup for extracting "waste" heat during the generation of electrical power is shown in Figure 4.

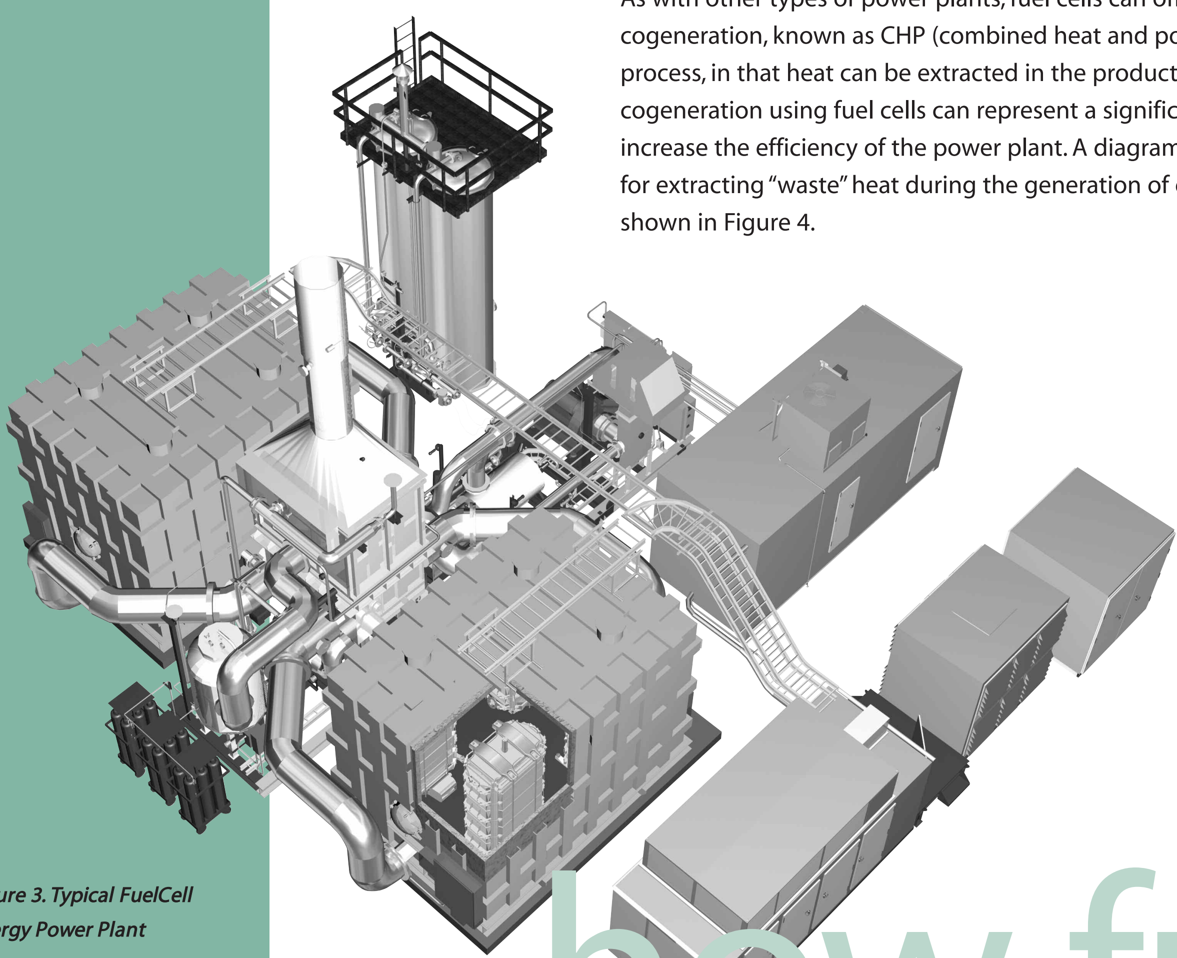

Figure 3. Typical FuelCell Energy Power Plant

how fuel

Direct FuelCell power plants have an exhaust temperature ranging from 650°C to 750°F. This heat energy can be captured to provide heat for buildings, swimming pools, and other facility needs. In fact, the already high efficiency of fuel cells can be increased from around 47% to as much as 80% or more, depending on design and installation parameters.*

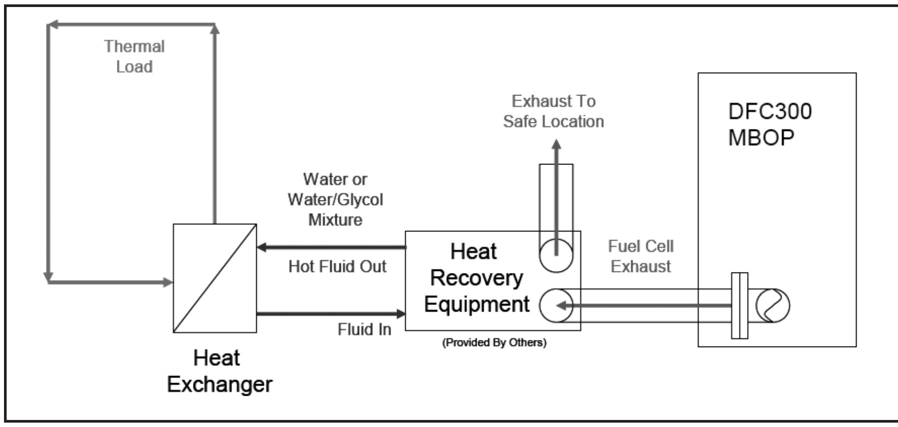

Figure 4. Diagram of a CHP Setup for Extracting Heat During Fuel Cell Power Generation

How important is CHP? According to the U. S. Combined Heat and Power Association, more than $5 billion dollars in heating costs are saved annually by building owners in the U. S., and energy consumption is being reduced each year by some 1.3 billion BTUs. While these figures cover all types of CHP, including systems incorporated in plants that burn fossil fuels, the benefits of cogeneration in a fuel cell operation are two-fold: 1) the increase in efficiency previously mentioned, and 2) the fact that Ultra-Clean, quiet fuel cell plants can be located within or near the facility where the electricity is to be used. This is a distinct advantage over conventional central plants that are usually located too far from heat users to allow for effective utilization of waste heat.

There are other CHP considerations regarding the tradeoff between heat and electricity that highlight the benefits of fuel cells over turbines and other combustion generators. Electricity generated during a cogeneration process has a significantly greater value than that of the associated waste heat, in fact, up to 10 times as much. Thus, the generation of electricity is paramount in the economic efficiency equation, since the more electricity that can be produced by the power plant, the less of this relatively high priced electricity must be purchased from the grid.

With traditional sources of power generation — e.g., reciprocating engines, microturbines, etc. — CHP can mask the underlying electrical power generation efficiency of the power source. Whatever CHP adds to the overall efficiency, economics will be driven by the actual electrical power-generating efficiency of the plant. Thus, in the case of a gas turbine, operating at 25% electric power generation efficiency and a reciprocating engine at 35% electrical power generation efficiency, considerably less of the overall output of the system — percentage wise — is in the form of electricity. In contrast, the Direct FuelCell operates at 47% electrical power generation efficiency. The bottom line: fuel cells offer the distinct advantage of a higher ratio of electricity to heat — electricity that would be relatively expensive if it had to be purchased from the grid — while capturing much of the waste heat generated for the CHP process.

** Alternatively, instead of the waste heat generated by the fuel cell being used for cogeneration, the heat can be transferred to a turbine, which converts the heat to mechanical energy and then to electrical energy. Such a process can increase electrical efficiency by 10 to 15 percentage points. Simpler power generation bottoming approaches, such as powering an Organic Rankine Cycle (ORC) with DFC exhaust heat, can increase electrical efficiency by 2 - 3 percentage points. In a system where DFC waste heat is provided to support gas distribution pressure letdown (DFC-ERG), efficiencies in the mid-60% range can be achieved. These types of heat to electricity approaches are effective in larger grid connected applications where there may not be a local user of thermal energy.*

At the Leading Edge of Technology with Direct FuelCells

Some 60 stationary power plant installations using FuelCell Energy's DFC fuel cells supply baseload power in five countries. To date, the company's DFC systems have produced more than 180 million kilowatt hours of electric power for customers. Facilities in which systems have been installed include hospitals, hotels, wastewater treatment plants, prisons, food and beverage processing plants, manufacturing plants, universities, government institutions, and utilities.

For these types of applications, fuel cell technology, and in particular, FuelCell Energy Direct FuelCells, offer important performance and cost-saving benefits over traditional methods of generating power. For example, in *food and beverage processing,* digester gases are produced by the fermentation of organic matter. Direct FuelCells can use the methane from the digester gas to produce electricity and heat (which is used by the digesters). This avoids the need to flare unused gas, and provides power in a much cleaner manner than if the gas were used in a combustion-based generator.

Hospitality represents another market for which fuel cells are especially suited. The success of a hotel depends largely on its ability to provide an attractive, clean, and quiet environment. Virtually silent and unobtrusive, fuel cells provide "Ultra-Clean" baseload power to the hotel, while simultaneously generating heat as a usable byproduct for swimming pools, domestic hot water, and building heat. The presence of this "green" technology is also seen by the hotel industry as a unique marketing opportunity: some companies request that their employees only stay at "green" hotels.

Manufacturing plants employ fuel cells for both baseload power and peak load management. Waste heat produced in power generation is often used in the manufacturing process to augment or replace existing heating systems.

The *medical industry*, including hospitals, nursing homes, and other critical care facilities require reliable baseload power around the clock, and they have a need for cogeneration heat. Ultra-Clean, quiet fuel cells offer a viable alternative to dependence on conventional fossil fuel-based utilities for baseload power.

Prisons have well defined power and heat loads, and benefit from the reliability gained by paralleling a fuel cell powerplant with the grid. A power loss at one of these facilities would cause concerns about security, even though short-term backup systems exist. Many prisons also house a medical facility, for which reliable power and heat is essential.

Wastewater treatment plants produce biogases that are released in the form of atmospheric emissions. Fuel cells take advantage of the biogas by reforming it into usable hydrogen that provides a source of fuel for the fuel cell power plant. The biogas is thus consumed and emissions are negligible.

By all standards of measurement, FuelCell Energy is the leading manufacturer of stationary fuel cells in the world. The reasons for this encompass more than company size, capability, and years of experience. They are based on two factors: a) the innovation and advancements in fuel cell technology pioneered by FuelCell Energy, and b) participation by the company with government agencies, such as the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) and the Solid State Energy Conversion Alliance (SECA), in technology research and development. Such co-development efforts have led to global recognition for the company's achievements in advanced research in such areas as solid oxide fuel cells (SOFCs) and the successful development and commercialization of the Direct FuelCell.

At present, FCE manufactures three fuel cell systems: DFC300MA, DFC1500, and DFC3000. The DFC300MA provides 300 kW of continuous power output. Suitable applications for this product include supermarkets, medium-sized (300-bed) hotels, and small commercial businesses. The DFC1500 produces 1.2 MW of continuous baseload power. It is ideal for large hotels, convention centers, and facilities with similar levels of power consumption. The DFC3000 produces 2.4 MW of baseload power. The unit is designed to meet the power needs of hospitals, universities, large manufacturing complexes, and utility/grid support. Multiple DFC systems can be combined to provide larger power outputs for large utility/grid support applications up to 50 MW.

FuelCell Energy also supplies DFCs for a unique grid support application through its distributor, Enbridge, Inc. In this application, the Direct FuelCell is combined with a turbo expander to extract energy at natural gas letdown stations. Known as the DFC-ERG, the product is commercially available. Other high-performance systems, such as the high efficiency Direct FuelCell/Gas Turbine hybrid (DFC/T), are in developmental stages

Some of the advancements and enhancements in technology that help to distinguish Direct FuelCells include the following:

• DFCs create the hydrogen gas needed by the anodes within the fuel cell module from readily available hydrocarbon fuels, such as natural gas. This process is called internal reforming, and external equipment (which adds cost and requires energy input) is not required.

  Internal reforming is possible due to the relatively high operating temperature (650-750°F) of Direct FuelCells. This operating temperature has other advantages. For example, because of the high temperature, non-precious metals can be used for the anode and cathode instead of platinum, resulting in significant cost savings. Also, the exhaust from the system is high-grade heat, capable of supporting a variety of heat recovery options, including steam generation.

• DFCs can run on natural gas, or biogas, such as digester gas from wastewater treatment and food processing plants. Some states consider fuel cells running on biogas to be a renewable energy source, which means the fuel cells qualify for additional financial incentives. With adjustments to the system, DFC plants can also run on propane, diesel fuel, ethanol, coal gas, and other hydrocarbons.

• FuelCell Energy's DFC power plants are complete systems, which include all of the "balance of plant" equipment needed to convert natural gas or treated digester gas into grid quality electricity. Simply stated, this means all aspects of the plant, including accessories and supporting equipment — heat exchangers, power electronics, control logic, and even valves, fittings, piping, etc. — have been designed and selected to optimize the complete power system package.

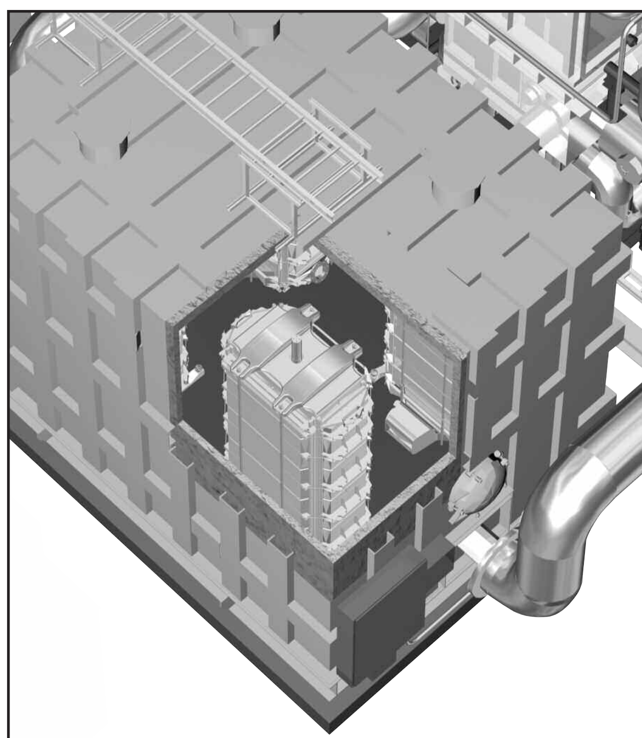

Figure 5. Cutaway Illustration of a Direct FuelCell Module Showing Individual Cells in a Stack

Distributed Generation

Distributed generation is a term for a power generating source located close to where the power is required, as opposed to centralized power generation supplied through the grid. Centralized power generation plants can be located hundreds of miles away from the consumer and serve a number of states.

Today, most of the electricity produced in the U.S. is provided by regional utilities and supplied to customers via the grid. As a matter of fact, of the 3,800 billion kilowatt hours (kWh) of electricity produced in the U.S. in 2003, only 4.1% (156 billion kWh) was non-utility generation. 3.6% (135 billion kWh) was produced by industrial companies to meet the local power needs, and the remaining 0.5% (21 billion kWh) was attributable to other sources.

Slowly, however, the landscape is changing, because of the distinct advantages of distributed power generation. Commercial businesses and institutions — hotels, universities, and government facilities, to name a few — are choosing to become self-reliant in terms of energy needs. Doing so provides a degree of flexibility not otherwise possible, and reduces grid congestion and power transmission issues associated with centralized generation.

There is another advantage of distributed generation: as mentioned, a DG fuel cell power plant with CHP capabilities allows for the use of waste heat generated by the fuel cell to heat the building, thus reducing energy costs. Finally, there is the possibility, depending on the state, of being connected to the power grid and selling back excess power not required by the local user. Where net metering is permitted, energy costs can thereby be further reduced.

For a facility looking to install a DG power plant to meet baseload requirements, a DFC power plant offers the advantage of compactness, quiet and reliable operation, competitive operating costs, and "Ultra-Clean" emissions.

Conclusions

The Direct FuelCell is a perfect fit for a number of emerging markets that require a technology that can provide Ultra-Clean distributed generation over a range of sizes. With few exceptions, the worldwide community of nations recognizes the impact that pollution is having on the environment, and demand for electricity produced without harmful emissions is growing. While alternative sources of electrical energy are generally viewed in the role of backup power, fuel cells are beginning to take center stage for baseload power in DG applications. FuelCell Energy is at the forefront of such progress and is certain to remain so with the company's continually evolving Direct FuelCell technology and products.

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